2000 Progress Report

1. <u>Principal Investigators</u>
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3. <u>Title of Research Grant</u>
Refinement, Validation and Applications of Cloud-Radiation Parameterizations in a GCM
(DE-FG03-94ER61748)

4. <u>Science Goal</u>

The goal of this research is to develop and implement a new radiation parameterization scheme in a GCM and utilize ARM data to test the performance of the scheme. The steps toward this goal include:

A. Ongoing refinement of the scheme developed;

B. Introduction of accelerated methods of computation;

C. Improvement to optical property parameterizations;

D. Development of a validation strategy including use of CART data and participation in model comparison activities.

5. <u>Progress/Accomplishments</u>

- Implemented the new radiation scheme in the CSU GCM. This new scheme is now being adopted as the principle radiation scheme of that model.

- Refinement of rapid 3D-line-by-line Monte Carlo simulations of various cloud types for testing the model.

- Participate in the 3D radiative transfer intercomparisons and this 3D scheme ICRCCM III intercomparison effort.

5.1 Two-stream radiative transfer parameterization

Within the past twelve months, the Stephens Group's two-stream radiative transfer model that is the primary radiative transfer scheme of the Colorado State University General Circulation Model has been tested and improved. As presented at the Tenth ARM Science

Team Meeting in San Antonio, several two-stream approximations were tested and their performance was judged in the context of typical GCM-produced input parameters including optical depth and single-scattering albedo.

The two-stream code has undergone many changes to increase speed when run for multiple GCM columns. Timing tests have been performed on the two-stream code and compared with results from the Harshvardhan scheme as originally applied in the CSU-GCM.

Another important aspect of the new two-stream code has to do with its inclusion of infrared multiple scattering. Neglecting this effect, as most GCM radiation schemes do, leads to errors in outgoing, atmospheric absorbed, and surface downwelling longwave radiation as indicated in Figure 1. This represents a significant and unaccounted-for bias in these models.

5.2 Acceleration methods for radiation parameterization scheme

Methods for accelerating the computation of fluxes have been developed and tested. These methods include the adjoint perturbation approach and the method of selection rules.

Properties of the selection rules have now been characterized and fully implemented in the CSU-GCM. This work extends the development described in the adjoint perturbation work by including the framework for rapidly calculating broadband IR fluxes. The combination of selection rules (solar and longwave) and standard two-stream solver results in what we call the hybrid model. The selection rule criteria requires that there be either strong absorption or weak scattering.

5.3 Three-dimensional transport development

We have developed a Monte Carlo radiative transfer model that simulates the transport of solar radiation through an atmosphere consisting of three-dimensional distributions of cloud and/or aerosols embedded in a profile of absorbing gases. This model employs the equivalence theorem which, by keeping track of path length information, allows spectral flux calculations to be performed at any wavelength resolution. By integrating stored path length probability distributions, absorption due to gas is incorporated into the calculation after the Monte Carlo portion of the code has been run. It is through this separation of the gaseous attenuation that both high-spectral resolution and model speed are possible.

The current Monte Carlo/Equivalence Theorem code is being run on the Cray T3E multi-processor computer at the Geophysical Fluid Dynamics Laboratory (GFDL). We are working with the group headed by V. Ramaswamy to use their shortwave line-by-line gaseous absorption database in this model.

The model has undergone several modifications in the past two years to increase its speed and accuracy while decreasing its use of computer memory. Along with the use of this code by us and the GFDL group to do research involving three-dimensional radiative transfer, we are using it as one of the benchmark algorithms in the Intercomparison of Radiation Codes in Climate Models (ICRCCM), Phase 3. A version of the model is also an active participant in the Intercomparison of the Three-Dimensional Radiation Codes (I3RC).

6. Selected Highlights of Current Research

- Figure 1 shows the zonally averaged broadband LW fluxes introduced by the common assumption that IR scattering by clouds is negligible. The global mean bias introduced to OLR exceeds 8 WM^{-2}.

- Figure 2 highlights the computational performance of the radiation scheme expressed in terms of the number of layers that defines the vertical model resolution. The essential character of the scheme is linear in layer as opposed to other schemes that are more typically quadratic in layer.

- Figure 3 shows area-averaged downwelling line-by-line spectral solar fluxes (middle panel) for a model atmosphere containing a 3D cloud distribution (upper panel). The spectral fluxes were determined using full-up 3D radiative transfer based on methods developed as part of this research.

7. Refereed Publications Acknowledging this Research Grant

1. Barker, H., Q. Fu, and G. L. Stephens, 1999: The sensitivity of domain averaged fluxes to assumptions about cloud geometry. *J. Quant. Spectrosc. Radiat. Transfer*, **125**, 2127-2152.

2. Gabriel, P. M., P. T. Partain, and G. L. Stephens, 2000: Parameterization of Atmospheric radiative transfer, Part II: Selection rules. Submitted to: *J. Atmos. Sci.*

3. Gabriel, P. M., G. L. Stephens, and I. Wittmeyer, 2000: Adjoint perturbation and selection rule methods for solar broadband two-stream fluxes in multi-layer media. *J. Quant. Spectrosc. Radiat. Transfer*, **65**, 693-728.

4. Partain, P. T., A. K. Heidinger, and G. L. Stephens, 2000: High spectral resolution atmospheric radiative transfer: Application of the equivalence theorem. *J. Geophys. Res.*, **105**, 2163-2177.

5. Partain, P. T., S. D. Miller, and G. L. Stephens, 2000: On the consistency between modeled and measured solar flux reflected by clouds. Submitted: *J. Atmos. Sci.*

6. Stephens, G. L., 2000: Radiative Effects of Clouds and Water Vapor. Chapter 3.1: Water Vapor. In Press: *Global Energy and Water Cycles,* Cambridge University Press, New York, NY.

7. Stephens, G. L., P. M. Gabriel, and P. T. Partain, 2000: Parameterization of atmospheric radiative transfer, part I: Validity of simple models. Submitted: *J. Atmos. Sci.*

8. Young, S. A., C. M. R. Platt, R. T. Austin, and G. R. Patterson, 2000: Optical Properties and Phase of Some Midlatitude, Midlevel Clouds in ECLIPS. *J. Applied Meteor*, **39**, 135-153.

8. List all published (either paper or web-based) extended abstracts in the current FY that acknowledge DOE ARM support. Two copies of each should accompany the progress report*.

- Simple Computational Acceleration Methods for Longwave and Shortwave Broad-band Fluxes Multilayer Media. P. D. Gabriel, P. T. Partain, and G. L. Stephens, 2000. *Proceedings of the Tenth Atmospheric Radiation Measurement (ARM) Science Team Meeting.* San Antonio, TX, March 13-17, 2000 (Extended Abstract in Preparation).

9. Please update us on the status of submitted referred publications from the previous FY progress report. (If none, note "NONE").

1. Platt, C. M. R., S. A. Young, P. J. Manson, G. R. Patterson, S. C. Marsden, R. T. Austin, and J. H. Churnside, 1998: The optical properties of tropical cirrus from observations in the ARM Pilot Radiation Observation Experiment. *J. Atmos. Sci.*, **54**.

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Fig. 1

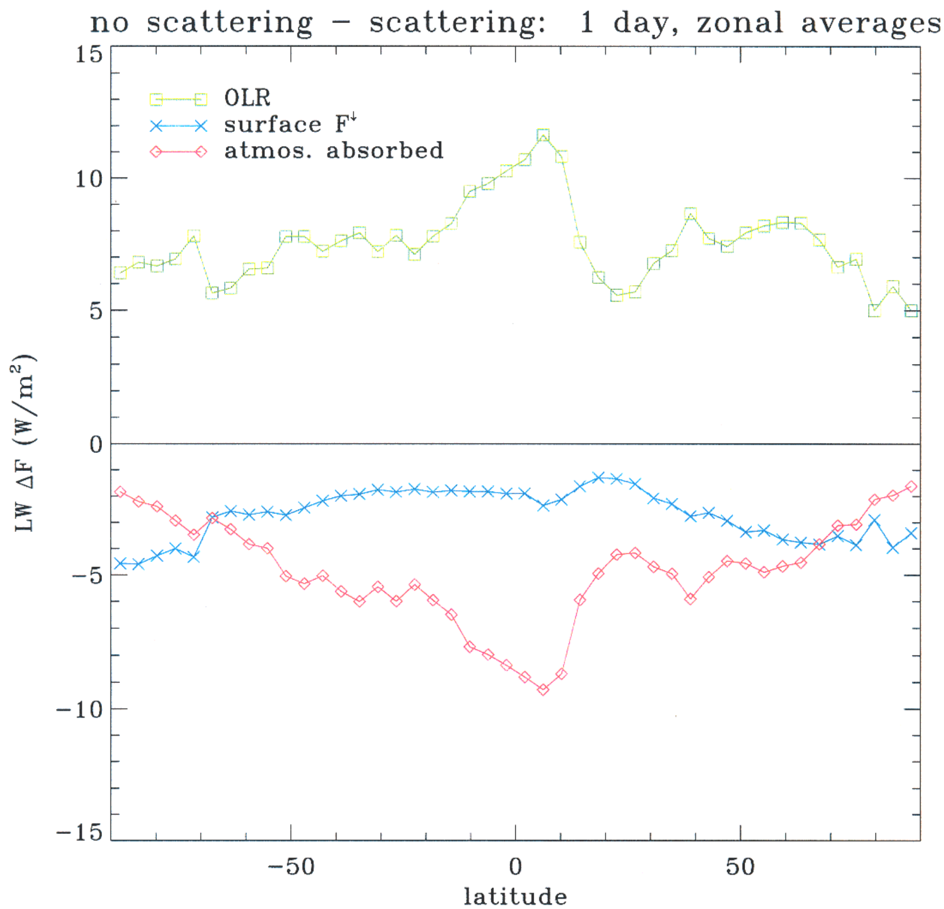

Figure 1: The zonally averaged broadband LW fluxes introduced by the common assumption that IR scattering by clouds is negligible. The global mean bias introduced to OLR exceeds 8 WM^{-2}.

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Fig. 2

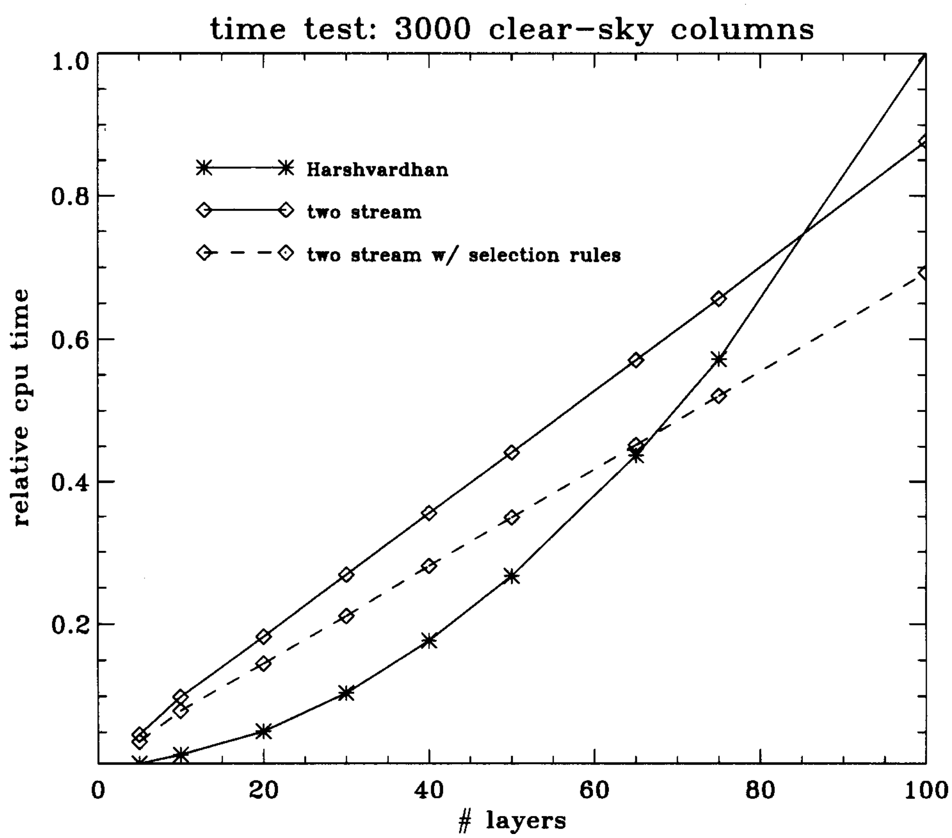

Figure 2: Highlights the computational performance of the radiation scheme expressed in terms of the number of layers that defines the vertical model resolution. The essential character of the scheme is linear in layer as opposed to other schemes that are more typically quadratic in layer.

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Fig. 3

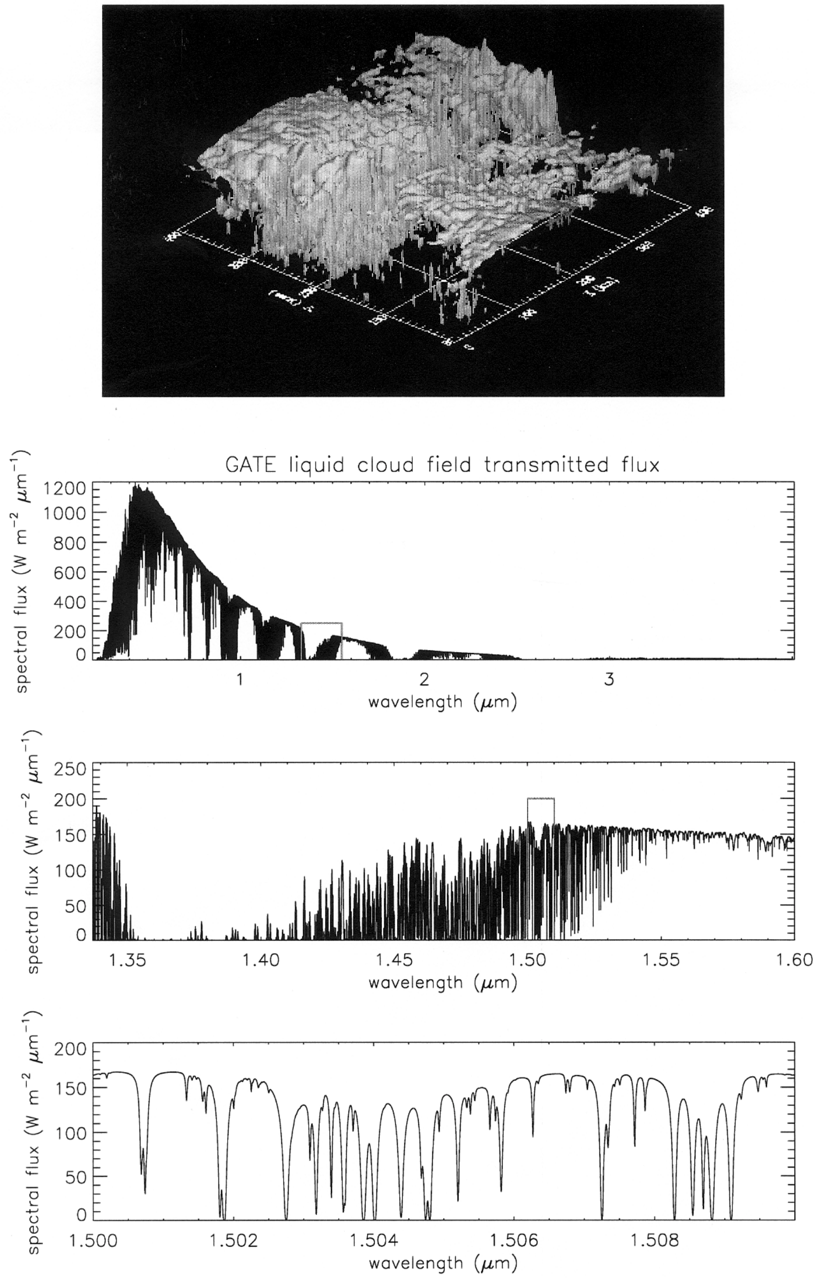

Figure 3: Area-averaged downwelling line-by-line spectral solar fluxes (middle panel) for a model atmosphere containing a 3D cloud distribution (upper panel). The spectral fluxes were determined using full-up 3D radiative transfer based on methods developed as part of this research.